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Antenna systems for the 'Aryabhata' mission

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Abstract. The onboard and ground antenna system employed in the *Aryabhata* mission for telemetry and telecommand operations are described. The onboard antenna system common to telemetry and telecommand frequencies consists of four monopoles fed in turnstile configuration and generates a near isotropic pattern with worst dips of the order of -10 dB over approximately 0·2% of the total radiation sphere area. The ground antenna system consists of a high gain (16 dB) telecommand antenna and a telemetry array of eight medium gain Yagis (gain 22 dB).

Keywords. Antennas; electromagnetics; satellites.

1. Introduction

The antenna system employed in the *Aryabhata* mission for telemetry (TM) and telecommand (TC) operations falls under the following two categories: (1) satellite onboard antenna systems, (2) ground antenna systems.

An onboard antenna system with a near-isotropic pattern both at telemetry (137·44 MHz) and telecommand (148·25 MHz) frequencies was required to meet the communication link needs between a ground station and *Aryabhata*. The requirement for an isotropic pattern was dictated by the fact that the satellite had no attitude control and hence it could take any possible orientation with respect to the ground station during its life in space. A true isotropic pattern is an ideal situation and in practice only approximate isotropy can be realised. The type of approximation is governed by the type of antenna system selected, nature of mount and the size of the body on which the antenna is mounted. The onboard antenna being near-isotropic, to have reliable up-and downlinks, either the respective power of transmitter should be high or the ground station antenna gain should be high. In the case of uplink (telecommand), to some extent, it is possible to have high power transmitter at the ground but the practical constraints to achieve the high power are quite severe and hence a trade-off between the TC transmitter power and the antenna has to be made. The link calculation to account for the worst case onboard condition for maximum slant range showed that a reliable uplink can be established for a ground TC transmitter power of 1 kW and an antenna gain of 16 dB. For downlink, the onboard transmitter power is very limited, essentially restricted by the available onboard d.c. power. From the link calculations for 600 km circular orbit and for the radiated

power of 1·5 W by the onboard transmitter, it was found that an antenna of gain 22 dB would suffice for a reliable downlink.

2. Satellite onboard antenna system

The system chosen after considerable study (Brown and Woodward 1947; ESRO-Report 1971; Jasik 1961; Kraus 1950; Pal and Saha 1971; Anon 1967) was that of four quarter wave monopoles made at the mean of telemetry (137·44 MHz) and telecommand (148·25 MHz) frequencies, i.e. 142·85 MHz mounted around the belly band of the satellite and operated in turnstile fashion. The dimensions of the dynamic envelope of the heatshield of the rocket were insufficient to contain the satellite with quarter-wave monopoles mounted perpendicular to the spin axis. This made it necessary to mount the monopoles in an inclined fashion and 45° inclination was chosen as the best value, balancing the inclination and the image effects due to body reflections. The maximum length of the monopoles which could be accommodated was 560 mm (0·257λ at 137·44 MHz where λ is the wavelength). Any further increase in length, if required, could be achieved by bending the monopoles at the tip parallel to the spin axis to compensate the effect of oblique images of monopoles in the satellite body. Figure 1a (plate 1) gives the configuration of the monopoles

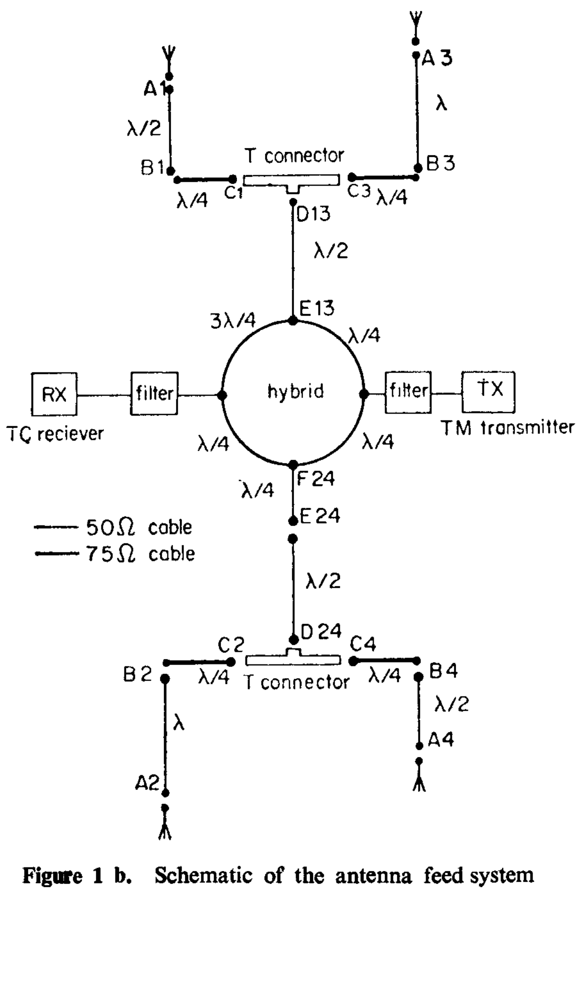

Figure 1 b. Schematic of the antenna feed system

mounted on the belly band of a rhombocubic octahedral satellite with an inclination of 45°.

The feed system using a ring hybrid was designed for : (i) simultaneous handling of telemetry and telecommand signals and (ii) providing a sequential 90° phase shift for four monopoles. The complete feed system is shown in figure 1b.

3. Experimental study of the onboard antenna system radiation pattern

Since it is easier to match the impedance than to get the required radiation pattern, an experimental study was undertaken to evaluate the radiation characteristics of the antenna system. Because of the ease of measurement at higher frequencies, the study was made on a 1/3 scale model. The antenna system was made to operate over the frequency band 412·32 and 444·75 MHz (3 times the telemetry and telecommand frequencies respectively). The hybrid coupler was made at 412·32 MHz to give maximum isolation between the transmitter and the receiver port at 412·32 MHz. By experimentation the length of each monopole for minimum dip in the gain pattern

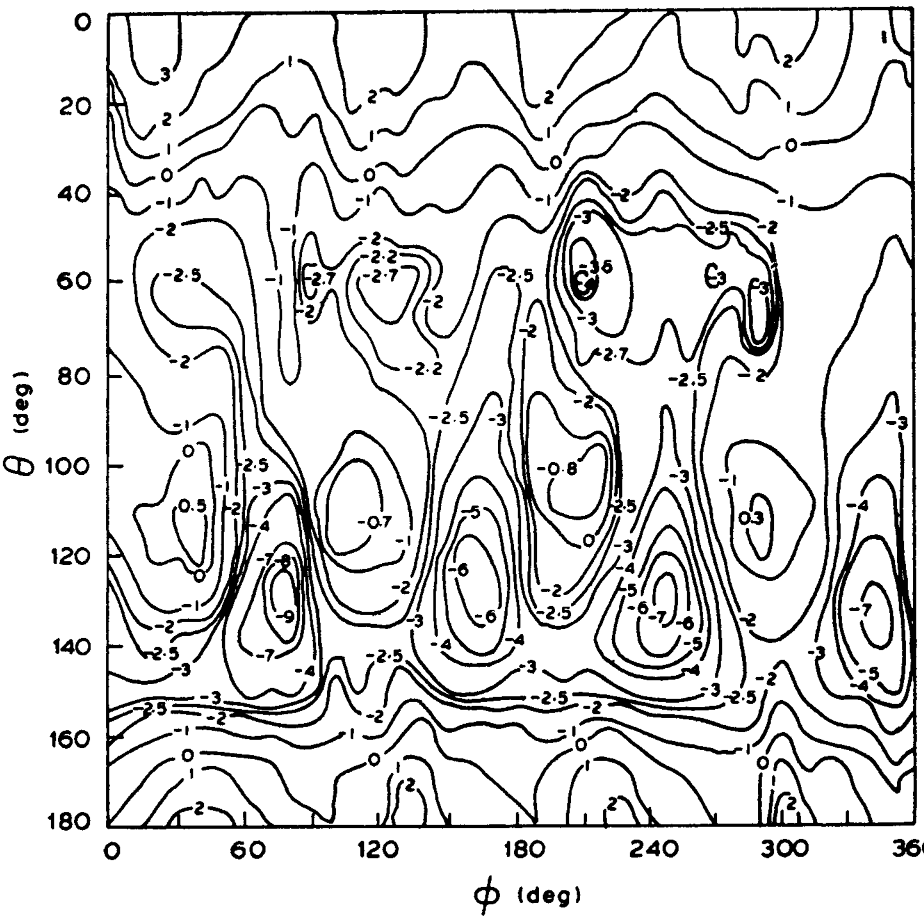

Figure 2. Onboard antenna gain (dB) characteristics at telemetry frequency (contour plots)

was found to be 0·257 λ (straight)+0·0274 λ (bent) at 412·32 MHz. Since there was more margin at the telecommand frequency, manipulation of the phases of the monopole excitations was considered without tampering with phase symmetry, for improvements at 412·32 MHz. Cable harnesses were made at different frequencies to examine the effect of feed phase on the radiation pattern. The cable harness made at 420 MHz (3 × 140 MHz) resulted in a gain pattern with near −10 dB dips at both frequencies.

The radiation pattern measurements were made for vertical and horizontal polarisations at both frequencies covering the entire radiation sphere. A standard dipole was used as a reference. The worst dips observed for vertical and horizontal polarisations were of the order of −20 dBi at both frequencies, where dBi stands for decibels over isotropic level.

The gain patterns are calculated for diversity reception (Pal *et al* 1976) by combining the results of vertical and horizontal polarisations at each θ and ϕ. The results are presented in the form of contour plots in figures 2 and 3, at the telemetry and telecommand frequencies, respectively. The overall radiation characteristics were found to accord with expectations. There are four dip zones in the upper hemisphere around

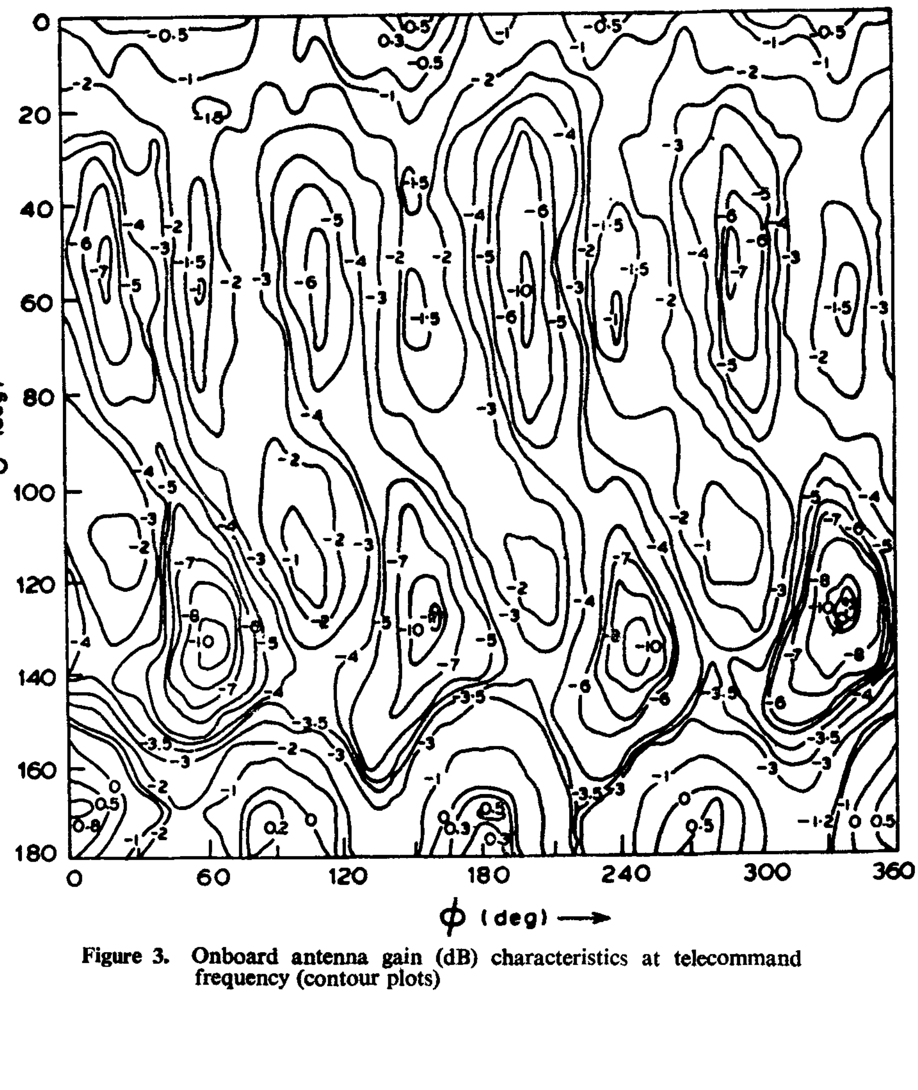

Figure 3. Onboard antenna gain (dB) characteristics at telecommand frequency (contour plots)

θ=50° to 60° and an additional four in the lower hemisphere around θ=130° to 140° of the omni-radiation sphere. These dip regions are symmetrically placed around the spin axis with an approximate interval of 90°. The null depths are more in the lower hemisphere than in the upper one, which is due to the fact that the antenna system faces more blockage from the lower part of the satellite body than in the upper. Maximum gain is obtained along the spin axis.

Using figures 2 and 3, the percentage of total surface area radiating a certain level is calculated. Such percentage areas for different gain levels at both frequencies are presented in figure 4. From this, the average gains at both frequencies are calculated and these are below the isotropic levels. Efficiencies calculated from these values, which include the feeder mismatch losses and the dissipative losses at the monopoles, are 73% at telemetry frequency and 64% at telecommand frequency.

4. Impedance measurements and final tests

Impedance measurements were carried out on a full scale satellite model. The impedances at the monopoles were of the order of 50 ohm with voltage standing wave ratio

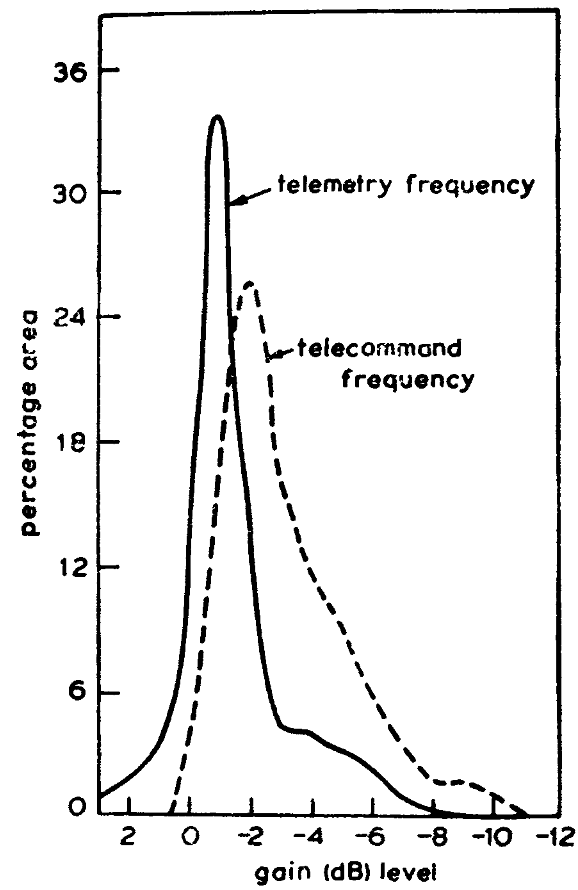

Figure 4. Percentage areas at different gain levels

less than 2·0 at both frequencies. The voltage standing wave ratio at hybrid ports were found to be less than 1·2 for both frequencies.

Activated solar panels were fixed on the satellite to study the effect of the circulating currents on the impedances. The effect was found to be negligible. It was expected that these panels do not have any effect on the radiation pattern either. This was confirmed in actuality.

The final full scale antenna system was qualified after subjecting it to various environmental and mechanical tests according to the following specifications:

temperature range	$-10°C$ to $+55°C$
pressure	10^{-5} torr
vibration and acceleration levels	0·2 to 10 g

5. Performance in orbit

After the satellite was placed in orbit, antenna patterns were evaluated from the recordings of automatic gain control (AGC) outputs of two telemetry receivers, and a post-detective type diversity combiner. The two telemetry receivers were connected to two orthogonal linear polarisations. Figure 5 indicates samples of combined patterns, taken at different intervals, in orbit No. 664. The results are

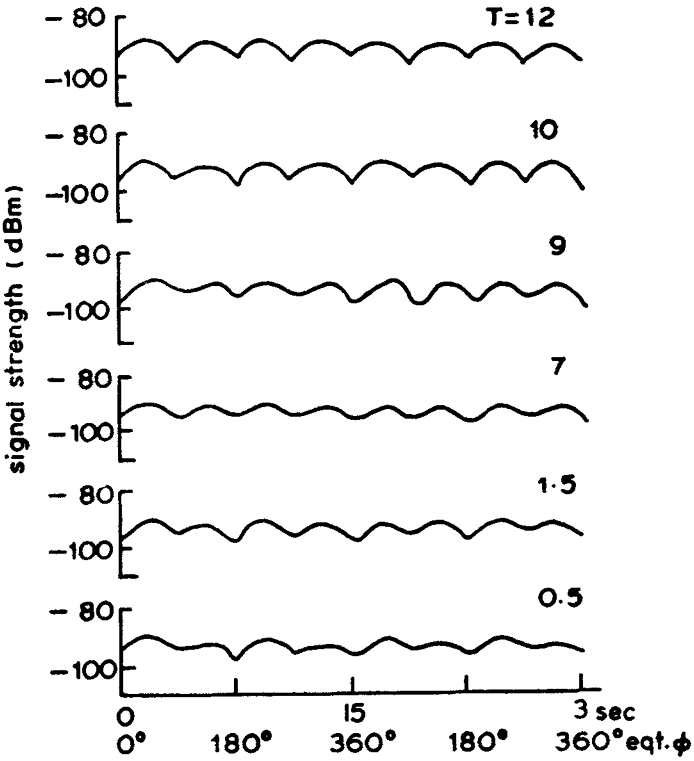

Figure 5. Combined antenna patterns at different intervals of time (T min) during the pass

Table 1. Satellite on board antenna specifications

A. Electrical characteristics		
	Telemetry	*Telecommand*
Frequency (MHz)	137·44	148·25
Type	Turnstile	Turnstile
Maximum gain on axis (dBi)	+3	+2
Pattern	Near omni-directional	Near omni-directional
Null depth for diversity combination (dBi)	−10	−11
Null depth for single linear polarisation (dBi)	−20	−20
Surface area with gain −10 dBi	0·188%	0·023%
Impedance (ohm)	50	50
Voltage standing wave ratio	<1·3	<1·3
Polarisation (on +Z axis)	Right circular	Left circular
(dBi=dB over isotropic)		
B. Mechanical characteristics		
Mount	Monopoles mounted at 45° to the spin axis around the belly band, with a suitably designed mount. 560 mm of straight length +60 mm of 45° bent length (parallel to spin axis) (0·257λ straight + 0·2274λ bend at the tip, λ=2·18 m)	
Weight	330×4 g	
Material	Al—2024	

quite comparable to the measurements made on the 1/3 scale model. The worst dip observed in orbital performance was around −10 dB in the gain pattern for diversity reception, and around −30 dB for any single linear polarisation reception. The worst dip of −30 dB is very sharp and hence was not observed below −20 dB on the 1/3 scale model study due to ground reflections and use of a less sensitive receiver.

There is no comparable method of evaluating the performance at telecommand frequency. From the scale model study, it is evident that the performance at both frequencies is more or less identical. Also, since all the commands are operating on the satellite in orbit, it can be safely assumed that the performance of the antenna system at telecommand frequency is also according to expectations.

The spacings of the dips in the AGC recordings can be used to calculate the spin rates. The approximate orientation of the spin axis can also be estimated from the pattern recordings.

In summary a satellite antenna system having the specifications and performance characteristics described in table 1 have been designed and flown onboard *Aryabhata.*

6. Ground telecommand and telemetry antenna systems

Since the onboard antenna system is common to both telemetry and telecommand frequencies and since it also has near isotropic radiation pattern, the ground stations

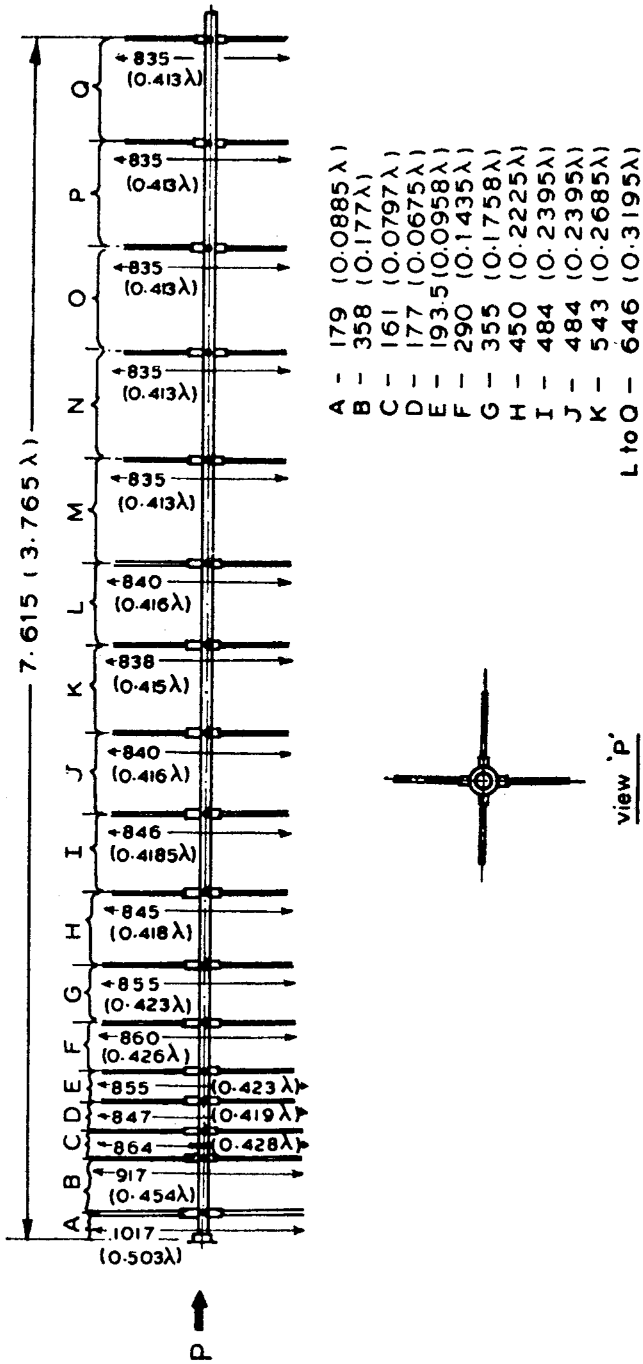

Figure 6. Telecommand antenna assembly

antennas have to be of a high gain. From the up- and downlink calculations based on telecommand transmitter power of 1 kW and telemetry transmitter power of 1·5 W, it was found that a 16 dB telecommand antenna and a 22 dB telemetry antenna would ensure the reliability of operations.

An extensive study was made to achieve these high gain antennas at VHF. It was found from previous studies (Jasik 1961; Wolf 1967; ARRL Handbook) that in VHF range, the Yagi antenna system is best suited considering the electrical and mechanical characteristics of different antenna systems. The required high gain could be achieved either by a single Yagi antenna or by an array of medium gain Yagi antennas.

In the case of telecommand antenna (required gain 16 dB) a single Yagi was preferred over an array to achieve 16 dB gain purely from the point of view of mechanical mounting. It was easy to manoeuver a single Yagi and also it was possible to mount it at the centre of the telemetry antenna array. However, a single Yagi will be very unwieldy for more than 16 dB gain as at axial lengths greater than 4λ, the gain increase is negligible with increase in axial length. Hence, it was decided to have the telemetry antenna of 22 dB gain by arranging medium gain Yagi elements.

7. Telecommand antenna

The telecommand antenna designed was a cross linear polarised antenna. A

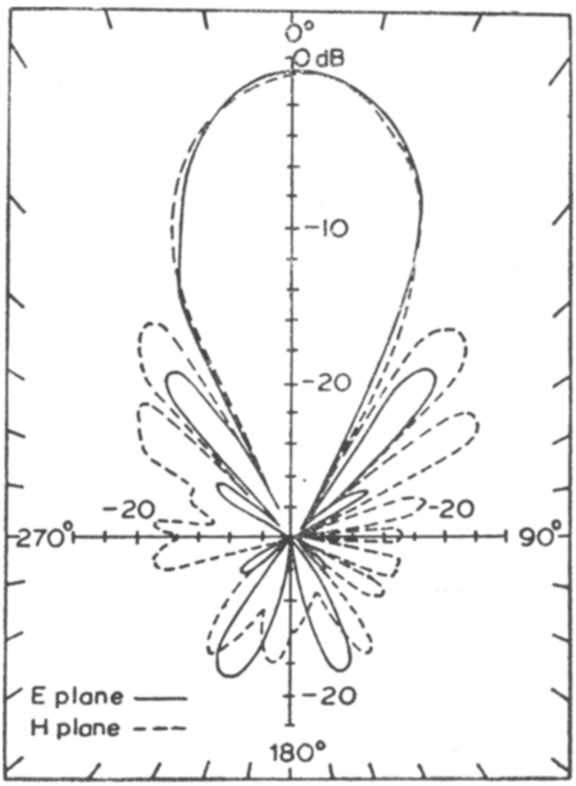

Figure 7a. Radiation pattern of telecommand antenna for linear polarisation A and B.

Table 2. Telecommand antenna specifications

Type	: Yagi (17 elements, 3·66 λ long)
Frequency	: 148·25 MHz
Maximum gain	: 16±1 dB over isotropic
Impedance	: 50 ohms
Voltage standing wave ratio	: <1·25
Pattern (E/H planes)	
Beam width	: 30°
Maximum side lobe level	: −16 dB
Back lobe level	: −20 dB
Power handling capacity	: 2 kW average
Band width	: 12 MHz
Polarisation	: Provided with crossed elements resulting in two orthogonal linear polarisation. An external polarisation switch is used to obtain right or left circular polarisations.
Connectors	: N type (female)
Physical description	
Total length	: 7·615 m
Maximum width	: 1·017 m
Material	: Commercial aluminium
Weight	: 25 kg

polarisation switch was put at the input of the antenna to achieve left or right hand circular polarisation of the transmitted signal. In the initial phase the antenna element lengths and spacings were adjusted by experimentation to achieve maximum design gain (16 dB) and optimum axial length. Radiation pattern measurements in ground reflection modes were carried out for both the linear polarisation and corresponding patterns were plotted both for E and H planes. Figure 6 gives the dimensional sketch of the final developed antenna and figure 7a the typical E and H radiation plots for polarisations A and B. Table 2 gives the overall specifications of the telecommand antenna. The results of the measurements indicate that the design is nearly optimum compared to a normal design (Jasik 1961; Wolf 1967; ARRL Handbook) and hence it can be adopted for similar gain requirement conditions after proper scaling. Figure 7b (plate 2) shows the photograph of the telecommand antenna designed and developed at ISAC which is currently being used at Sriharikota Ground Station for sending commands to *Aryabhata*.

8. Telemetry antenna system

The available telemetry antenna system at Sriharikota, which had servo drive and provision for auto tracking was used after some modifications to suit our requirements. This antenna is an array of eight medium gain (14·7 dB) Yagi elements

Table 3. Ground station telemetry antenna specifications

Frequency	: 136–138 MHz
Gain	: 22 ± 1 dB
Front to back ratio	: 20 dB
Side lobes	
E plane	: -12 dB
H plane	: -10 dB
Beamwidth:	
E plane	: $12{\cdot}5° \pm 0{\cdot}5°$
H plane	: $13{\cdot}0° \pm 0{\cdot}5°$

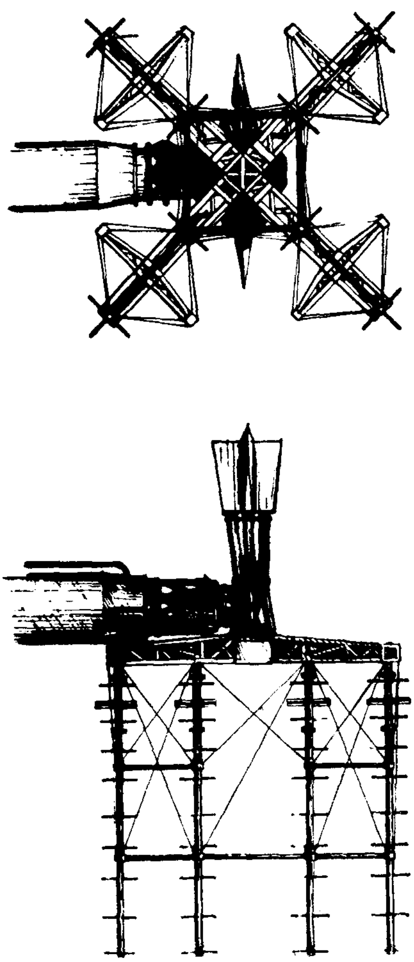

Figure 8. Telemetry antenna array

arranged in the manner shown in figure 8. Table 3 gives the characteristics of the total array.

Figure 9 shows the typical radiation pattern of the antenna array. A photograph of the antenna appears in Rao (1978).

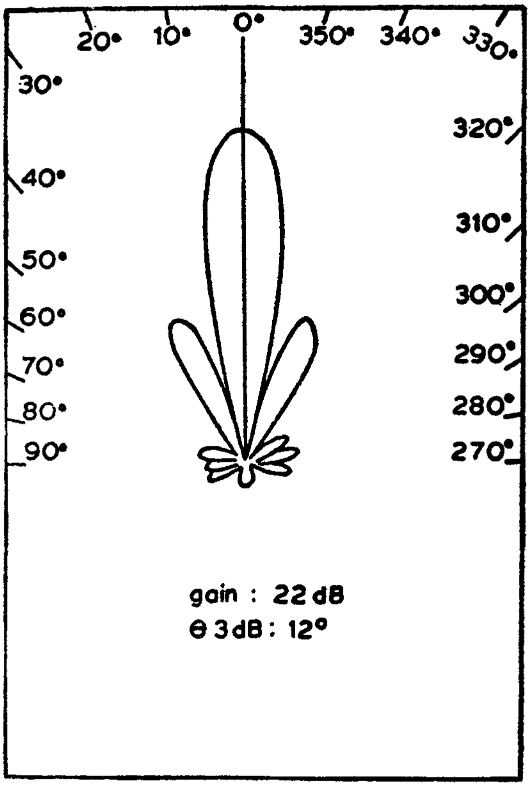

Figure 9. Typical pattern of the telemetry antenna

9. Conclusions

The antenna systems, both onboard and ground, were found to be compatible and fulfilled the design requirements during the actual orbit operations of the satellite. In the case of telemetry reception, the signal could be acquired at elevation angles even lower than 5°.

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Plate 1

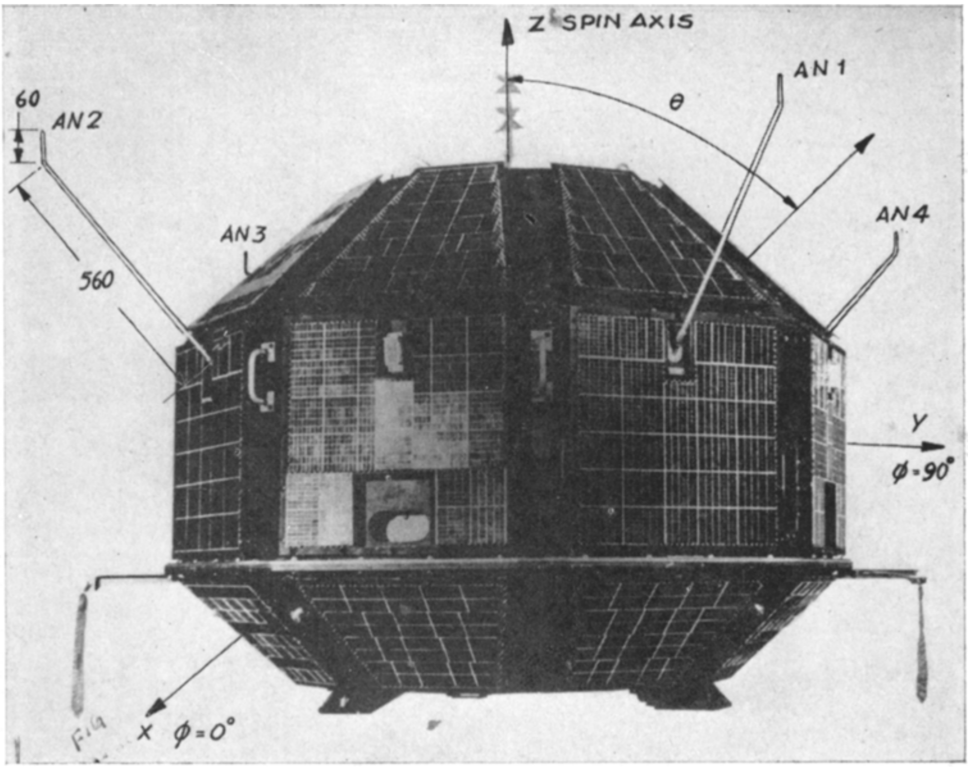

Figure 1a. Satellite with antennas mounted

Plate 2

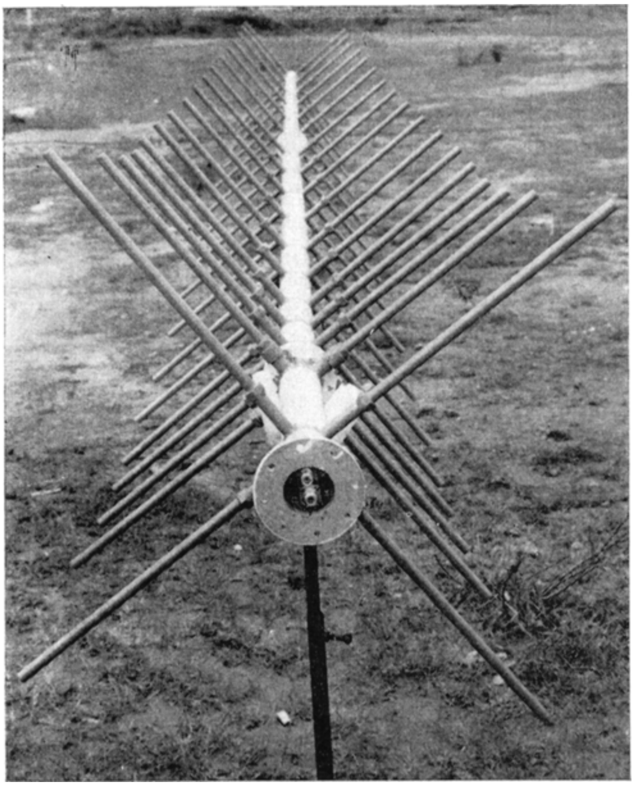

Figure 7b. Photograph of telecommand antenna